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Region**

Forest Pest Management Report

R3-95-02

**INSECTS AND DISEASE:
INDICATORS OF FOREST HEALTH**

A FOREST HEALTH BRIEFING PAPER

PREPARED BY

FOREST PEST MANAGEMENT STAFF

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INSECTS AND DISEASE: INDICATORS OF FOREST HEALTH

A FOREST HEALTH BRIEFING PAPER

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INSECTS AND DISEASE: INDICATORS OF FOREST HEALTH

INTRODUCTION

Most insects and diseases affecting forests in the Southwest are naturally occurring components of forest ecosystems. As such, they play an important role in the dynamic processes of forest ecosystems. They function in nutrient release, organic matter recycling, and in enhancement and retardation of succession (Byler et.al. 1992). They also provide food and habitat for animals, affect short and long-term structural diversity, and contribute to the biological diversity of the system.

However, when their numbers increase to outbreak or epidemic levels and result in adverse effects on resource management objectives, including ecosystem sustainability, forest insects and diseases may also be considered harmful pests. Likewise, chronic high levels of insects and diseases may be an indication of unhealthy forests and forest ecosystems that are out of balance.

While outbreaks of naturally occurring insects and diseases have no doubt occurred throughout the forests of the Southwest for eons, the incidence and severity of some have been at relatively high levels over the past few decades, figure 1. In addition, the introduction of exotic agents, such as white pine blister rust, will also have significant impacts on Southwestern forest ecosystems.

MAJOR INSECT AND DISEASE OCCURRENCES

Dwarf mistletoes are the most widespread disease-causing agents in the Southwestern Region (Fairweather and Frank, 1992). Approximately 1,040,000 acres of National Forest lands are infected by dwarf mistletoes in Arizona, and 1,140,000 in New Mexico (Johnson, 1988). Dwarf mistletoes are parasitic flowering plants that depend on their hosts almost completely for water and nutrients. They slowly weaken and eventually kill the host tree. There are many different species of dwarf mistletoe, all belonging to the genus *Arceuthobium*, and generally each one infects a specific tree species. Most Southwestern conifers are parasitized by dwarf mistletoes (Fairweather, 1990).

Dwarf mistletoes can spread to susceptible trees near infected ones via explosively discharged seeds that can commonly travel as far as 40 feet. The rate of spread of dwarf mistletoe is a function of stand age, density, and site index, and averages 1 to 2 feet a year in evenaged ponderosa pine stands. Spread is most efficient and rapid from an infected overstory to a susceptible understory (Hawksworth, 1961). Prior to European settlement, wildfires were a primary factor in determining the distribution and intensity of dwarf mistletoes in coniferous forests. Fire exclusion policies during the past half century may have increased both infection levels and fire hazard (Alexander and Hawksworth, 1974).

Effects of infection by dwarf mistletoes include: growth loss; mortality; reduced cone and seed production; reduced seed viability; and ecological effects such as rate and direction of stand succession and enhanced food and habitat for wildlife (Hawksworth et al, 1989; Bennetts, 1991; Severson, 1986; Zwickel et. al., 1974). Growth is reduced markedly as the level of infection increases (Hawksworth, 1961). Mortality of infected trees is also related to infection levels and tree size (Hawksworth and Geils, 1990). Tree decline and mortality caused by these parasites also impact aesthetic qualities at recreation sites and in visual corridors (Rogers and Conklin, 1991). Some of the changes in forest structure brought about by dwarf mistletoes can be beneficial to wildlife species. The abundance of birds and species richness of bird communities were enhanced by dwarf mistletoe infection in central Colorado (Bennett, 1991).

Dwarf mistletoes tend to have negative effects on timber production. Estimated annual volume loss in infected ponderosa pine forests is over 25 million cubic feet on all Federal lands in the Region (Fairweather and Frank, 1992). Effects of dwarf mistletoes on Douglas-fir, Engelmann and blue spruce, and on pinyon pine are also significant, but have not been adequately quantified. Recent surveys suggest that the incidence of dwarf mistletoe has increased over the past thirty years, figure 2, due to human activities such as suppression of wildfires, inappropriate harvesting practices, and lack of priorities for treating infested stands (Fairweather and Frank, 1992; Maffei and Beatty, 1988). If timber and prescribed fire activities are reduced or forgone, dwarf mistletoe infestations can be expected to intensify over time (Parmeter, 1978).

Root diseases affect conifers throughout the Southwest (Wood, 1983). They are caused by decay fungi, such as *Armillaria* spp., *Heterobasidion annosum*, *Inonotus tomentosus*, and *Phaeolus schweinitzii*. Root diseases are a management concern on approximately 1.1 million acres in the Southwest (USDA, Forest Service, 1985) and are responsible for approximately 10 percent reduction in growth and yield Region-wide. Estimates range as high as 25 percent in some seriously infected stands. Annual root disease mortality in the Southwest is at least 15 to 20 MMBF, with estimates as high as 45 MMBF, including growth reduction, figure 3, (Rogers and Hessburg, 1985). This roughly equates to 100,000 to 150,000 trees per year, most of which occur in the mixed conifer and spruce/fir ecosystems.

Root diseases are becoming more of a problem as we manage our forests more intensively (USDA, Forest Service, 1985; Hagle and Goheen, 1988). Root diseases typically persist on a site for decades by surviving in roots of stumps (Tkacz and Baker, 1991) and as residents on infected roots of live trees. Regeneration can become infected through root contact with infected residuals from the previous stand. Armillaria can also infect by means of windborne spores that infect freshly cut stumps or basal wounds (Otrosina and Cobb, 1989), but it more commonly infects via root contacts and root-like structures (rhizomorphs) that grow through the soil and can penetrate root bark (Shaw and Kile, 1991). Some root diseases can kill young trees rapidly (especially those planted off-site), but others slowly decay the roots and rob the trees of water, nutrients and structural support. Infection by root diseases results in reduced growth, increased mortality (often by bark beetle attack), altered stand structure, and, sometimes, large openings in forests. After a half century of fire exclusion

and selective harvesting, the incidence of root disease is increasing in mixed conifer stands in the Intermountain Northwest as ponderosa pine, a species that is relatively insect and disease resistant, is replaced by Douglas-fir and true firs, species that are much more prone to infection by root diseases (Hagle and Goheen, 1988). Similar shifts in species composition are occurring in Southwestern mixed conifer stands.

Western spruce budworm (Choristoneura occidentalis) outbreaks have occurred at irregular intervals throughout mixed conifer and, to a lesser extent, spruce/fir stands in the Southwest for at least the last 300 years, and probably much longer. Tree ring studies of mixed conifer stands in the Colorado Front Range and New Mexico Sangre de Cristo Mountains indicated at least nine outbreaks of WSB occurred from 1700 to 1983 (Swetnam and Lynch, 1989). The results of their study indicate that a change in budworm incidence has taken place in the twentieth century compared with earlier years. While the frequency of moderate to severe outbreaks during this century is not clearly less or more than during previous centuries, the spatial and temporal pattern of occurrence has changed. Outbreaks have become more synchronous over the host type. This evidence suggests that budworm outbreaks have become more extensive in recent years. It is thought that the synchroneity of outbreaks in the more recent years is due to changes in age structure and species composition (widespread establishment of younger multi-storied, shade tolerant, budworm host susceptible trees) following widespread harvesting and the beginning of fire suppression around the turn of the 1900s (Swetnam and Lynch, 1989).

Western spruce budworm outbreaks have more or less persisted in mixed conifer and some spruce/fir areas, namely the Kaibab and Apache-Sitgreaves NFs in Arizona, and the Carson, Santa Fe, Cibola, Lincoln, and Gila NFs in New Mexico since 1975. Since then, acres of annual defoliation have fluctuated from a low of 9800 acres in 1975 to a high of 692,000 acres in 1984. Acres of WSB-caused defoliation in 1991 totaled 248,000, figure 4.

Several years of intensive defoliation can result in radial growth loss, top-killing, reduced seed and cone production, and some tree mortality. In addition, stand structure and composition, and regeneration are altered by western spruce budworm outbreaks. Other affected resources include visual quality, recreation, and wildlife habitat.

Growth loss attributed to western spruce budworm outbreaks on the Carson NF was assessed in 1983 through dendrochronological analysis of increment cores extracted at breast height (Swetnam 1983). This analysis revealed that host-tree growth was reduced during past and present budworm outbreaks. The average growth loss for five-year periods during outbreaks was approximately 30 to 40 percent and the maximum growth loss during one year was generally greater than 50 percent.

Top-killing is directly related to a combination of defoliation intensity and total number of years of consecutive defoliation (Rogers 1984). Results of an ongoing western spruce budworm damage assessment project on the Carson National Forest show that in 1981, after only three years of repeated defoliation, top-killing had occurred on 12.3 percent of the seedlings, 10.3 percent of the sapling, 7.3 percent of the poles, and 4.3 percent of the sawtimber (Stein and McDonnell 1982). In 1982, following one more year of defoliation, top-

killing had increased to 29.1 percent of the poles and 16.8 percent of the sawtimber (Rogers 1984); top-killing of seedlings and saplings was not measured in 1982.

Seed and cone loss may reach 100 percent in severe outbreaks and the ability of surviving trees to produce seed may be compromised for several years following an outbreak.

Repeated heavy defoliation can eventually result in mortality, particularly of trees stressed by other factors such as suppression, root diseases and dwarf mistletoes. A western spruce budworm impact survey conducted in the Red River drainage, Carson NF, NM, in 1984 and 1991 showed mortality was light, 3.5 percent, over the 25,700 acres where defoliation had been light to moderate. However, on the remaining 9300 acres, where repeated defoliation had been heavy for several years average WSB-caused mortality was in excess of 40 percent of the basal area, and in some individual stands, said mortality exceeded 75 percent of the total basal area (Klein and Bennett, in draft).

Additional amounts of significant mortality may also result from subsequent bark beetle attacks and outbreaks. These outbreaks, like the one experienced in Red River Canyon, occur when trees are stressed and predisposed to bark beetle attack by a combination of factors such as repeated defoliation, other pests, harsh growing sites, and abnormal weather patterns.

Repeated defoliation may also lead to changes in stand structure and composition. Stand structure may change as tree mortality, which is generally more prevalent in the smaller, suppressed understory trees, reduces the number of trees in the understory and increases the average diameter of trees in the residual stand. Stand composition may be shifted towards less susceptible Douglas-fir, spruce, nonhost pines, and aspen, as the more susceptible true firs are predisposed to defoliation-related mortality (Brooks et. al., 1985).

Regeneration may be seriously affected not only by the nearly complete destruction of seed and cone production during even periods of light defoliation, but also by the effects of direct feeding on established understory. These effects can be severe, even on advanced regeneration, and may reduce the success of various regeneration cuts.

Visual quality and recreational use are also affected by western spruce budworm outbreaks. Heavy defoliation and discoloration, and subsequent top-killing and tree mortality, may reduce the visual quality of scenic corridors and heavily used recreation areas. In addition, the presence of large numbers of larvae and moths may pose an undesirable nuisance to recreationists in developed campgrounds, picnic sites, and summer home areas.

The effects of defoliation on wildlife habitat and usage are varied and species dependent. Severe outbreaks may benefit insectivorous birds and mammals. Twenty six species of birds have been found to feed on the western spruce budworm in the northwest. Some species consume a considerable number of budworm larvae and pupae and can increase enormously on sites experiencing budworm outbreaks (Garton, 1987). Cavity nesting species may also benefit in areas where defoliation causes reduced tree crown cover, top-killing, and tree

mortality. Similarly, forage production, used by big game, may increase in areas of extended heavy defoliation and mortality. However, essential hiding and thermal cover may be reduced.

Bark beetle outbreaks occur periodically throughout all forest ecosystems within the Southwest. Most of the time, the greater proportion of the mortality they cause is the result of normal or endemic infestations that are continously present in mature forests (Furniss and Carolyn, 1977). These outbreaks are usually associated with stress factors such as overcrowded stands, root disease, and dwarf mistletoe; and are often triggered by drought or tree injury caused by logging, fire, or windthrow. While bark beetle populations have been relatively low over the past (relatively wet) decade, a few large outbreaks have occurred, killing thousands of trees over extensive areas. In general, these outbreaks occurred in areas where forest conditions were susceptible to outbreak, i.e. high stand densities and a preponderance of low-vigor, highly stressed host trees. Numerous researchers have reported an increasing risk of bark beetle epidemics with increasing stand density, increasing tree diameter and high moisture stress (Stevens et. al., 1980; Amman et. al. 1989; and Ferrell and Smith, 1976). When outbreaks do occur, they can kill vast numbers of trees over very large areas, and set the stage for devastating fires.

Numerous species of bark beetles affect forests in the Southwest, attacking all species of coniferous trees. Most are fairly host specific and are confined to primarily one tree species. Some of the more important ones include: *Dendroctonus rufipennis* Kirby, the spruce beetle, in engelmann spruce; *D. pseudotsugae*, the Douglas-fir beetle, in Douglas-fir; *D. brevicomis*, *D. ponderosae*, and *D. adjunctus*, the western pine beetle, mountain pine beetle and roundheaded pine beetle, in ponderosa pine; *Ips* spp. also in ponderosa pine; *Dryocoetes confusus*, the western balsam bark beetle, in subalpine fir; and *Scolytus ventralis*, the fir engraver, in white fir.

Historically, large bark beetle outbreaks have been a significant type of natural disturbance in certain forest types. For example, Baker and Veblen (1990) report that historic photos and tree dendrochronology data indicate that spruce beetle has been a major disturbance factor within the spruce type from Central New Mexico to North Central Colorado. Their report suggests that in many areas spruce beetle outbreaks may have played a role comparable to that of fire in pre-settlement forests. On the other hand, large outbreaks in the pine type may have been less common. Hopkins (1909) reports that in general the amount of tree mortality caused by bark beetles in the southwest was less than that observed in more northern and moist regions. However, exceptions to this have occurred. An extensive outbreak of mountain pine beetle was recorded on the Kaibab Plateau between 1917 and 1926 during which 300 million fbm of ponderosa pine were killed (Furniss and Carolin, 1977). In addition, periodic outbreaks in ponderosa pine occurred in the Jemez Mountains of northcentral New Mexico during the mid-1930s, the mid-1940s, and the late 1950s (Allen, 1989). These outbreaks involved both western pine beetle and Ips beetles and were usually associated with drought conditions.

In recent times two major spruce beetle outbreaks occurred in the 1980's. The White Mountain outbreak, primarily on Fort Apache Indian Reservation lands in Arizona killed an estimated 400,000 spruce over approximately 20,000 acres between 1981 and 1984 (Linnane,

1985). A second major spruce beetle outbreak occurred in the Pecos Wilderness of northern New Mexico between 1982 and 1985, killing an estimated 30,000 spruce over approximately 7000 acres (R-3 aerial survey records).

Other recent bark beetle outbreaks in the Southwest have included: Western pine beetle and Ips beetles on the Mormon Lake RD, Coconino NF, Arizona, during 1980-1982, that resulted in several thousand dead ponderosa pines over several hundred acres (FPM aerial survey records); an Ips beetle outbreak on the Apache-Sitgreaves NFs, Arizona, during 1990 and 1991, in which thousands of pinyon pines were killed over about a 24,000 acre area (Wilson and Tkacz, 1992); and two current outbreaks of western pine beetle and roundheaded pine beetle. One in the Sacramento Mountains of New Mexico, where an estimated 133,000 ponderosa pines have been killed over about 87,000 acres since 1990, figure 5 (Bennett 1992; T.J. Rogers, personal communication, 1993 aerial survey records); and the other in the Pinaleno Mountains of Arizona (Frank and Fairweather, 1994).

Bark beetle outbreaks result in a number of direct and indirect effects on forests. Some obvious effects include tree mortality, and top killing. In addition to causing mortality, bark beetle outbreaks can significantly modify the forest structure. Some species, such as spruce beetle, reduce the average age of surviving trees, lower the average diameter and height of the stand and the spruce component, lower the density, and leave suppressed and intermediate trees as the dominant or codominant spruce (Schmid and Frye, 1977). Outbreaks can affect successional changes in forests, promoting succession in some cases while setting it back in others. Effects on forest resources include: changes in biodiversity, decreased timber production and value, increased water yields, increased forage production, increased food and habitat for some wildlife species while decreasing the same for others, and increased fire hazard.

White pine blister rust is an exotic fungal disease that was discovered for the first time in the Southwest in March of 1990 on southwestern white pine near Cloudcroft, NM. Subsequent surveys indicate this disease is now present throughout most of the range of southwestern white pine on the Lincoln NF and the adjacent Mescalero Apache IR. Several areas on the Cloudcroft and Mayhill RDs are now experiencing heavy levels of infection. Some seedling and sapling mortality has occurred, and branch mortality (flagging) is common on all size classes of southwestern white pine. This disease will likely have a major impact on the white pine population and mixed conifer species composition of the Sacramento Mountains during the next several decades. Rust damage will become more and more noticeable during the next few years. Young trees will suffer more damage and will be more easily killed by the fungus than older, larger ones. In 40 to 50 years there will probably be many large white pines surviving, but there will be a deficiency in the smaller size classes throughout much of the affected area. Most of the now existing seedlings and saplings, and a lot of the poles, will have died. Regeneration will still occur, but most of it will succumb relatively quickly (Conklin, 1992). There is a potential for this disease to spread, either by man's activities or by windblow spores, to other area of southwestern white pine, limber pine, and bristlecone pine in the Southwest.

HISTORIC AND PRESENT FOREST CONDITIONS

Evidence suggests that the incidence of some disturbance agents has changed in recent years (Wilson and Tkacz 1993). These changes are thought to reflect changes in the underlying structure and function of forest ecosystems in the Southwest. The recent, relatively high levels of insect and disease activity in our forest ecosystems may be due in part to abnormal weather (either exceedingly wet or dry) and to past management activities such as fire suppression, selective logging, and a reluctance to adequately thin overcrowded stands. These practices have led to large, contiguous areas of dense, multistoried forests, often comprised primarily of late successional stage tree species. Such conditions result in low tree vigor and increased susceptibility to insect and pathogen attack, and greater risk of large scale outbreaks (Brooks, et.al. 1985, Furniss and Carolin, 1977; Schmid and Frye, 1977). These conditions currently exist throughout vast areas of our southwestern forest ecosystems, indicating that forest insect and disease outbreaks will continue, and perhaps increase, until susceptible stand conditions are altered (Pierson, 1931; Amman et. al., 1989; Massey et. al., 1977). Such alterations may result from the outbreaks themselves, from catastrophic fires, or from man's intervention through silvicultural manipulations (stand regeneration, thinning, prescribed burning, etc.)

Following is a description by forest ecosystem (cover type) of historic and current conditions and expected trends as they relate to risk of insect and disease outbreak:

Spruce-Fir

Historically, bark beetles and fire were among the major disturbance agents of the spruce-fir forest types in the Southwest. Prior to European settlement, these disturbance events were infrequent and high intensity (Covington and Moore 1992).

The majority of the spruce-fir forest ecosystem in the Southwest has not burned for over 100 years. A large portion of this ecosystem is densely stocked with large diameter spruce which are in excess of 150 years old and in a state of declining vigor due to stress from competition. As these forests continue to mature, the density of trees within them will to increase to the maximum "carrying capacity" for individual sites and their relative vigor will continue to decline. Trees growing under these conditions are increasingly susceptible to attack by wood decaying pathogens and to large-scale outbreaks of spruce beetle. Schmid and Frye (1977) consider spruce/fir stands at risk when the basal area exceeds 150 square feet per acre, average diameter is greater than 16 inches for live spruce over 10 inches in dbh, proportion of spruce in the canopy exceeds 65 percent, and when they are located in a well drained creek bottom or on highly productive sites (site index greater than 120). Such conditions exist throughout a significant portion of this forest cover type in the Southwest. These conditions could follow the hypothetical process of succession in the spruce-fir type involving spruce beetle that has been describe by Schmid and Hinds (1974). Under their hypothetical process spruce beetle outbreaks result in shifts in species composition, favoring subalpine fir over spruce. Over time, fir, a shorter lived species dies out and spruce again predominates, matures, and again is ripe for another spruce beetle outbreak.

Aspen

Aspen occurs in the southwest as a seral species, successional to a range of conifers, depending upon habitat type, including ponderosa pine, Douglas-fir, true firs, and spruce (Debyle and Winokur; 1985). The pathological rotation (or life expectancy) of these aspen stands is 90 to 120 years (Hinds and Wengert, 1977). As aspen stands mature, they become infected, often through natural or man-caused wounds, with a myriad of pathogens. The most serious pathogens which cause aspen mortality include stem cankers, stem decays, and butt rotting fungi. Stem decay and butt rot are more prevalent in trees greater than 90 years of age (Debyle and Winokur; 1985).

Most aspen stands in the Southwest are being replaced by more shade tolerant conifer species (listed above) due in large part to fire suppression. Foresters have attempted to regenerate aspen stands by coppice methods. However, in stands in Arizona, continued elk browsing of aspen sprouts has resulted in death of the suckering system due to depletion of food reserves. Aspen regeneration areas are now fenced in order to keep both elk and deer out. Ten of these fenced regeneration areas have been monitored for the past 3 years (Fairweather, in progress). Small pockets (1-3 acres) of aspen dieback were observed in many of these stands. Causes of dieback include frost, root rot, shepherd's crook, and elk damage (in one stand where the fence had been removed after 5 years).

Mixed Conifer

A significant, if not major proportion of our mixed conifer stands are highly susceptible to a number of potentially damaging insects and disease pathogens. This is borne out by the relatively high level of chronic western spruce budworm outbreaks and the widespread occurrence of dwarf mistletoes and root diseases which infect them. Those mixed conifer stands most susceptible to WSB are dense, unevenaged, mature stands, with white fir and Douglas-fir predominating the overstory, on mesic white fir habitat types or on other xeric sites (Linnane, 1986). In general, stand susceptibility increases as forest succession advances and net production of the stand decreases (Brooks, et.el. 1985). These same conditions may also enhance the spread and intensification of dwarf mistletoes, and reduce individual tree vigor, increasing susceptibility to root disease pathogens. Similar insect and disease activity is expected to increase in these mixed conifer stands as long as they remain susceptible to attack.

Ponderosa Pine

Prior to European settlement, disturbance events in the ponderosa pine type were frequent and low intensity (Covington and Moore 1992). Since that time the patterns have changes and resulted in different forest and insect and disease conditions (Covington and Moore 1992; Swetnam and Lynch 1989). These changes have resulted in ponderosa pine forests that are overstocked, stagnated, or have dense understories of young trees beneath the overstory (Wright, 1988). Such conditions reduce individual tree vigor, increase susceptibility to bark beetles and root diseases, and promote the spread and intensification of dwarf mistletoe.

The insects and diseases currently having the most effects on ponderosa pine in the Southwest in descending order of importance are: dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodum*), 43 percent of the
type; needle cast (*Lophodermella cerina*), 7 percent of the type; and bark beetles (*Dendroctonus brevicomis*, *D. adjunctus*, and *Ips* sp.), 3 percent of the type (Rogers and Conklin, 1991). There are an unknown number of acres that are affected by a combination of the above pests. Root diseases (*Armillaria ostoyae* and *Heterobasidion annosum*) are insidious pests that are present on many sites but it is hard to determine their annual effects. Their cumulative effect over time may be greater than some of the effects that are more obvious. Thirty percent of the mortality on five of the National Forests was due to root disease (Wood, 1983).

Outbreaks of bark beetles and needle casts occur when weather conditions are favorable. In the case of the bark beetles, droughts predispose pines to attack. Needle casts are favored by wet weather. Mistletoe and root diseases slowly infect a stand but persist over long periods of time. Pest effects will increase with time because stands are becoming more dense, stand structure has changed, and pine is occupying less favorable sites then what historically occurred. Over the last 55 years there have been at least six outbreaks of bark beetles (probably *D. adjunctus*) in the Lincoln National Forest (reported to have started on the poorest sites). From 1937 until the late 1960's these outbreaks involved 10,000 or fewer acres but since 1971 the outbreaks involved 100,000 and more acres or 10 times the previous acres (Pooler, 1938; Massey, et. al., 1977). Between the 1950's and the 1980's, the incidence of dwarf mistletoe in the commercial ponderosa pine type increased by 30 percent, based on a comparison of roadside surveys (Maffei and Hawksworth, unpublished).

Woodland

In general, insects and diseases are of minor importance in the oak or pinyon/juniper communities. However, like the other forest ecosystems previously discussed, as stands of pinyon and juniper continue to mature and increase in density, increased insect and disease activity can be expected. This will be especially evident during periods when trees are further stressed by other factors such as drought. A severe outbreak of pinyon Ips beetles occurred in the Bandelier National Monument area during the 1950s. The outbreak was associated with drought and killed 100 percent of the pinyon trees on many of the drier pinyon/juniper sites in the Frijoles watershed, where the pinyon trees were presumably under water stress

(Allen 1989). Wilson and Tkacz (1992) have reported that the timing of a recent pinyon Ips outbreak on the Apache-Sitgreaves National Forest was related to the severe drought in 1989-90. Once the outbreak began, the percent mortality was greatest in areas where basal areas were between 100 and 200 sq. ft. per acre. Pinyon dwarf mistletoe was also found at low levels. The percent of infected trees was somewhat greater in the areas where mortality was greater. Pinyon Ips attacked trees as small as 2 inches in diameter root collar (DRC) and as large as 11 inches DRC, but seemed to prefer trees between 7 and 11 inches DRC. High risk stands are those with basal areas between 100 and 200 square feet and many trees with DRC's between 7 and 11 inches.

Chaparral

Traditionally, Forest Pest Management has not been given responsibility for detecting, monitoring, or evaluating insect and disease situations in chaparral ecosystems as they usually contain few trees. However, a memorandum of understanding exists between the Forest Service and the Animal and Plant Health Inspection Service (APHIS), which gives APHIS the responsibility for monitoring, evaluating, and suppressing rangeland pests (FSM 1543.12 and 1543.13). Rangeland pests which may be found in this cover type include but are not limited to grasshoppers, Mormon crickets, grass bugs, rangeland caterpillars, chinch bugs and noxious weeds. Upon request APHIS may be able to furnish information concerning insects and pathogens affecting chaparral ecosystems.

Riparian

There are many insects and diseases associated with riparian ecosystems but few are known to have very damaging economic impacts. One of the most prevalent diseases in riparian areas is true mistletoe caused by *Phoradendron macrophyllum* which infects many riparian species including ash, cottonwood, sycamore, and walnut. Since mistletoe berries are a favored food source of several species of birds, severe build up of mistletoe is comon within an infected tree to which birds are attracted (Hawksworth and Scharpf, 1981). A high incidence of mortality in these severely infected trees has been reported in southern New Mexico (Sinclair et al, 1988).

Other diseases common in riparian communities are cyclic in occurance, outbreaks occur during years with abnormally high spring and summer rainfall. These include foliar and canker causing fungi. Rust fungi in the genus *Melampsora* cause premature leaf drop in cottonwood, impacting visual quality. Other species of *Melampsora* infecting willow can overwinter in buds which is believed to make shoots more susceptible to frost damage (Verwijst, 1989). Another important disease is sycamore anthracnose which causes leaf and shoot blight early in the season and later progresses into stem dieback and deformation of branches. These disease outbreaks rarely last for more than 2 years since abnormally high spring rainfall is uncommon in the Southwest.

DESIRED FOREST CONDITIONS

The desired forest condition for all forest ecosystems is one of good health. However, a healthy forest is very difficult to define and manage. Two differing perspectives on forest management form the basis for differing strategies to address forest health and the management of forest insects and disease. The first of these perspectives is objective driven and the second is based on an ecological approach.

Under the objective-driven approach, insects or diseases are monitored and direct suppression is attempted once thresholds of damage are exceeded. Pests are those organisms that interfere with the accomplishment of management objectives. **Forest health then is defined as a condition where biotic and abiotic influences on a forest do not threaten management objectives for an area now or in the future.** Integrated resource management dictates that the all resources be considered when managing the land since they are connected through an intricate series of interrelationships. Therefore, the effects of insects and diseases on all resources need to be evaluated and mitigated through prevention or suppression strategies.

Under the ecological approach, insects and diseases are considered to be integral components of the ecosystem that play important roles in the proper functioning of those ecosystems. **A healthy forest is an ecosystem in balance.** An outbreak of insects or disease can be symptomatic of an ecosystem out of balance and management should be focused on restoring the balance.

In reality, both these approaches need to be merged to successfully manage forests for the future. To be successful over the long term, management objectives must reflect ecosystem limitations. Human resource needs should be met within the long-term productive capacity of the natural ecosystems. Managing ecosystems requires an understanding of the functions, processes, and linkages of ecological systems. Forest insects and diseases have and will continue to be dominant agents of change in many forest ecosystems. Pest management decisions in the future will need to be based on "ecological thresholds" rather than on simple economic thresholds. These ecological thresholds require that we understand the patterns and boundaries of change in natural ecosystems.

POTENTIAL PRACTICES TO ACHIEVE DESIRED FOREST CONDITIONS

The following general practices are necessary components in the process to achieve desired healthy forest conditions for all forest cover types: 1) include and consider the ecological significance of forest insects and diseases in all forest resource management planning processes; 2) prevent resource losses and suppression costs by thinning (mechanically or through prescribed burns) overstocked stands to levels that will enhance tree vigor and reduce susceptibility to drought, insect outbreaks, the chronic occurrence of disease, and wildfires; 3) where appropriate, suppress insect and disease populations by sanitation cuts, salvage

cuts, stand regeneration cuts, or pesticide applications; 4) monitor the effects of insects and diseases as well as the effects of management techniques that are directed at insects and disease; 5) monitor the intensification and spread of introduced forest pests; 6) develop/ and implement plans to exclude exotic forest pests; and, 7) encourage active public involvement in considering resource management alternatives for forests threatened by insects, disease, and wildfire (USDA 1993).

Specific recommended practices and examples of successful implementation, where available, follow by cover type:

Spruce-fir

*create a mosaic of age classes across the landscape through prescribed burns, thinning, and/or stand regeneration methods.

Aspen

*regenerate decadent aspen stands and potential aspen stands (conifer stands where aspen is present and seral) using prescribed burns or clearcutting. The success rate may depend upon regenerating large continuous areas of fencing small areas to reduce the adverse effects of browsing.

*case example–Coconino NF.

Several attempts to regenerate aspen, in the 1970's and early 1980's, failed due to over-browsing of saplings by ungulates. Since the mid-80's, about 7 areas have been clearfelled and fenced. These range from about 5 acres to 40 acres in size. In 1990, personnel in the AZ-Zone office of FPM were requested to determine the causes of dieback which had occurred in 1-2 acre patches within a few of the regenerated areas. The causes of dieback varied between areas but included cold air drainages (frost), root disease, or decadence of original stand at time of treatment.

In October, 1991, a section of fence was removed from one of the areas, exposing about 6.5 ha, to test whether the trees were large enough to be out of reach of the animals. This regenerated stand, which had been fenced for about 5 years, averaged 50,000 stams/ha with dominant stems over 3 m in height. By October, 1992, most stems in one clone had been severely damaged by elk. The stems were snapped by the animals in order to reach the terminal foliage, often infecting the residual stem with Cytospora canker. Monitoring will continue to determine if the remaining clones will be browsed in future years. It appears that fencing must remain in place indefinitely in this ecosystem, given the demand for browse associated with current high animal populations.

see: Shepperd, W.D. and M.L. Fairweather

Mixed Conifer

*reduce tree densities, particularly in overcrowded understories, through prescribed burns or mechanical thinning to reduce competition, enhance tree vigor, and reduce susceptability to insects and diseases.

*encourage establishment and maintenance of seral species.

*sanitize or regenerate dwarf mistletoe infected stands.

*case example–Western Spruce Budworm Silvicultural Demonstration Area

In 1980, the Carson National Forest, in conjunction with Forest Pest Management and with the assistance of CANUSA, initiated a silvicultural demonstration area on the Taos Ranger District (since combined into the Camino Real Ranger District). The intent of the demonstration area project was to gain a wider acceptance of preventive management strategies for use against the western spruce budworm while meeting timber objectives. Silvicultural management systems demonstrated included clearcutting with planting, shelterwood seed-step cutting with planting, shelterwood seed-step cutting with protection of advanced regeneration, and shelterwood final removal cutting. In 1981, western spruce budworm larval and eggmass populations were sampled on plots within the four treatment and one untreated units. Defoliation estimates were also determined from sample trees located within these units. The western spruce budworm population collapsed and remained at very low levels in northern New Mexico between 1985 and 1992. Monitoring will resume on these treatment units if and when the western spruce budworm population increases.

see: Wulf and Rogers 1981; Rogers and Wulf 1982.

*case example–Western Spruce Budworm Permanent Plots

A series of permanent plots have been established in 27 stands, located within recent timber sales on portions of the Apache-Sitgreaves, Carson, Santa Fe, and Lincoln National Forests. One objective of establishing these plots is to evaluate the effectiveness of silvicultural treatments in reducing the susceptibility of the residual stand to western spruce budworm defoliation and subsequent damage. These plots will be monitored over several years.

Ponderosa Pine

*reduce tree density through prescribed burns or mechanical thinning to levels that will reduce competition, enhance tree vigor, and reduce susceptibility to bark beetle attack.

*kill and/or remove dwarf mistletoe infected overstories to protect established ponderosa pine understories.

*sanitize stands lightly infected with dwarf mistletoe.

*case example–Valle Vidal Biodiversity Project, Questa RD, Carson NF

The east side of the Valle Vidal Unit is characterized by dense, second-growth, pole-size stands of ponderosa pine. In late 1991 a shelterwood seed-cut was implemented to regenerate a 90 acre area heavily infected with Southwestern dwarf mistletoe. The resulting stand is open and park-like, featuring the best trees, and provides habitat diversity in an otherwise homogeneous landscape. About 100 older residual infected trees were burned to create wildlife snags. Once the area regenerates with healthy pine, the infected seed trees will be felled or killed. Diversity within the Unit should be enhanced with the development of another age-class of pine.

see: FPM 3420 letter evaluation of December 4, 1990; and, FPM 3420 letter evaluation of June 24, 1991.

*case example–2) El Rito Dwarf Mistletoe Control Project, El Rito RD
Carson NF.

A commercial timber sale took place in this area of high elevation ponderosa pine and mixed-conifer in 1990. Like much of this forest type throughout the Region, this area had been gradually converting from a pine to a fir type. One of the main objectives of the timber sale was to reduce stand densities to encourage ponderosa pine regeneration. Most of the merchantible pine infected with dwarf mistletoe, along with much of the merchantible white fir and Douglas-fir, was removed. The best of the larger pine were left in most stands.

Follow-up treatments in 1992 and 1993 removed dwarf mistletoe infected pine from the understory and thinned remaining stems (favoring pine where possible) to improve overall form and vigor. In addition to controlling dwarf mistletoe, this project has reduced the vulnerability of these stands to western spruce budworm, a chronic problem throughout northern New Mexico.

In 1993 we observed one and two year old pine regeneration in several portions of the sale area.

see: FPM 3420 letter evaluation of June 17, 1992.

*case example–Borrego Forest Health Project, Expanola RD, Santa Fe NF.

This project area was typical of many hundreds of acres on Borrego Mesa. A mature ponderosa pine overstory dominated the site, while a dense understory of pine and fir saplings were developing underneath. The project involved an understory thinning designed to create a more open, park-like stand, which research indicates is the natural structure for ponderosa pine in the Southwest.

In 1993 District crews cut intermediate and suppressed trees to provide fuelwood for local communities. A small proportion of the sapling understory was also cut, to increase dry fuels. The area will be prescribed burned this spring in an effort to "clean-out" much of the remaining understory. It is hoped that the area can be put under a periodic fire regime to enhance and maintain an open stand structure.

The project should increase the growth, vigor and longevity of the large overstory trees. Dwarf mistletoe infection levels have been reduced, and fire will be reintroduced into the ecosystem. We anticipate that the growth of understory vegetation–shrubs, forbs, and grasses–will be enhanced.

see: FPM 3420 letter evaluation of December 21, 1992.

*case example–Mars Hill Fuels Reduction Projects, Peaks RD, Coconino NF.
The main objective of the project was to reduce fuels in this ponderosa pine/ gambel oak forest type. Fire danger was extreme since the area is adjacent to the city of Flagstaff and many transcients camped there during the warmer months of the year. Damage potential was great because there is an observatory on site. The area also had a high level of mistletoe infection. The project was designed to reduce fuels while reducing mistletoe infection and competition between trees.

Woodland

*reduce tree densities through prescribed burns or mechanical thinning to reduce competition, enhance tree vigor, and reduce susceptibility to drought and bark beetle attacks.

Chaparral--no information.

Riparian-

*case example–*Melampsora* rust disease of Arizona willow.
Monitoring the effects of *Melampsora* rust disease on Arizona willow (*Salix arizonica* Dorn.), a candidate for listing as a threatened and endangered species, began in 1992. The effects of *Melampsora* rusts on the recovery of Arizona willow are being considered by the U.S. Fish and Wildlife Service.

see: Fairweather, 1993.

KNOWLEDGE GAPS

The longterm success of forest insect and disease management strategies will depend, at least in part, upon how well we understand and incorporate into our management, the effects of insects and diseases on the landscape now and into the future (Wilson and Tkacz 1993). To do so, we will need new knowledge and new analytical tools. We need to learn more about how insects and diseases affect and have affected ecosystems and ecosystem processes. We also need more knowledge about how our management strategies will affect insects and diseases and in turn the landscapes. We will need to understand these effects at different temporal and spatial scales. We will need reliable hazard rating models and predictive damage models to display the effects of insects and diseased on vegetation, and the ability to relate those effects to other resource specialists, managers, and our publics in terms they can understand and use.

Specific knowledge gaps include causes and prevention of aspen regeneration dieback; effects of thinning on susceptibility to western spruce budworm; rates of spread and intensification of white pine blister rust in the Southwest; determination of natural resistance of southwestern white pine to white pine blister rust; effect of unevenaged management on the spread and intensification of dwarf mistletoe; a measure of the effects of bark beetle outbreaks on TES species; effects of thinning to prevent Ips beetle outbreaks in woodland cover types; the effects of insects and dwarf misltetoe on pinyon nut production; an inventory of potentially harmful insects and diseases in chaparral and riparian areas; and a determination of the effects of insects and diseases on chaparral and riparian ecosystems.

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FIGURES

Annual Losses to Pests of Conifers

Southwestern Region

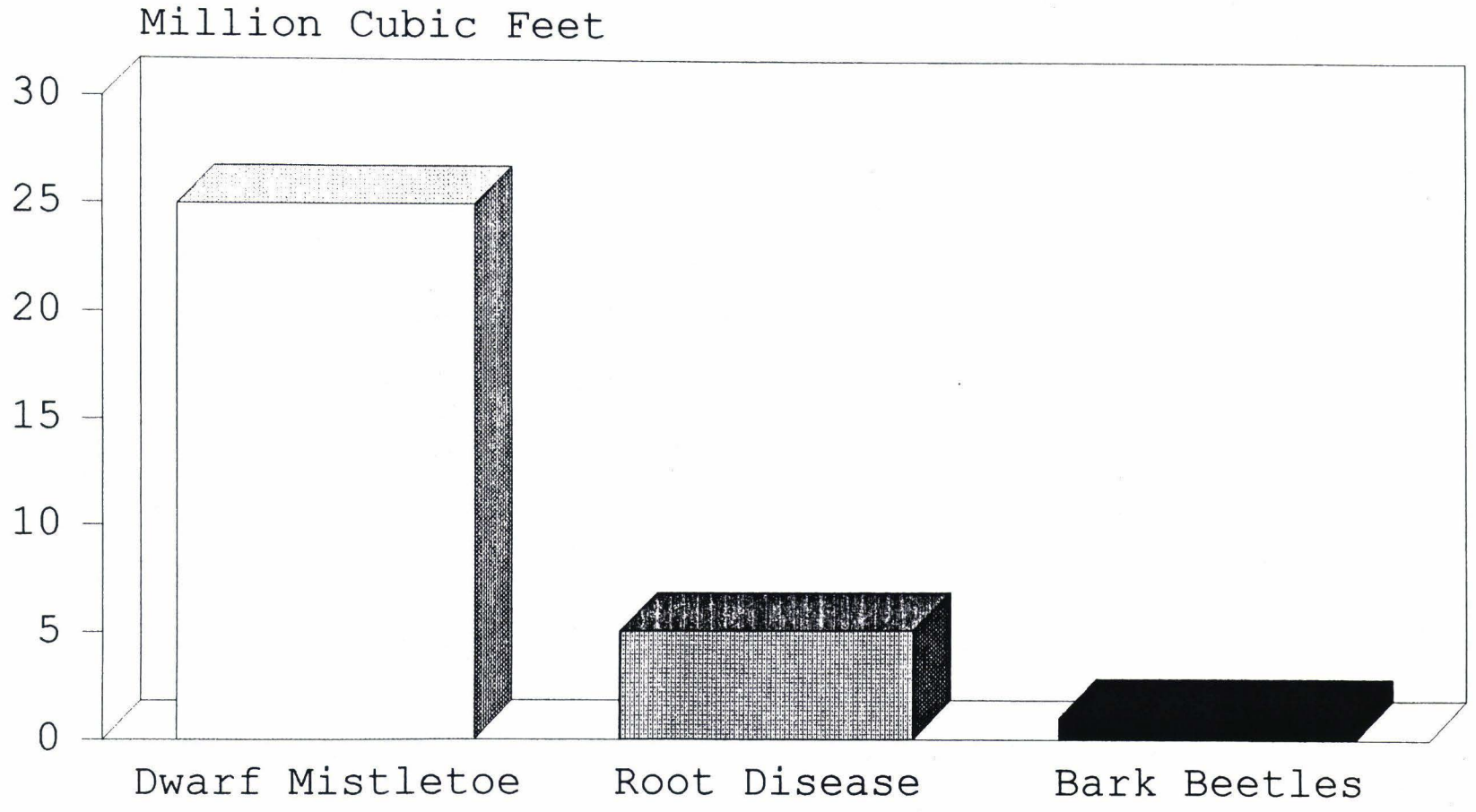

Figure 1

Distribution of SW Dwarf Mistletoe

Over Thirty Years on NF's in AZ & NM

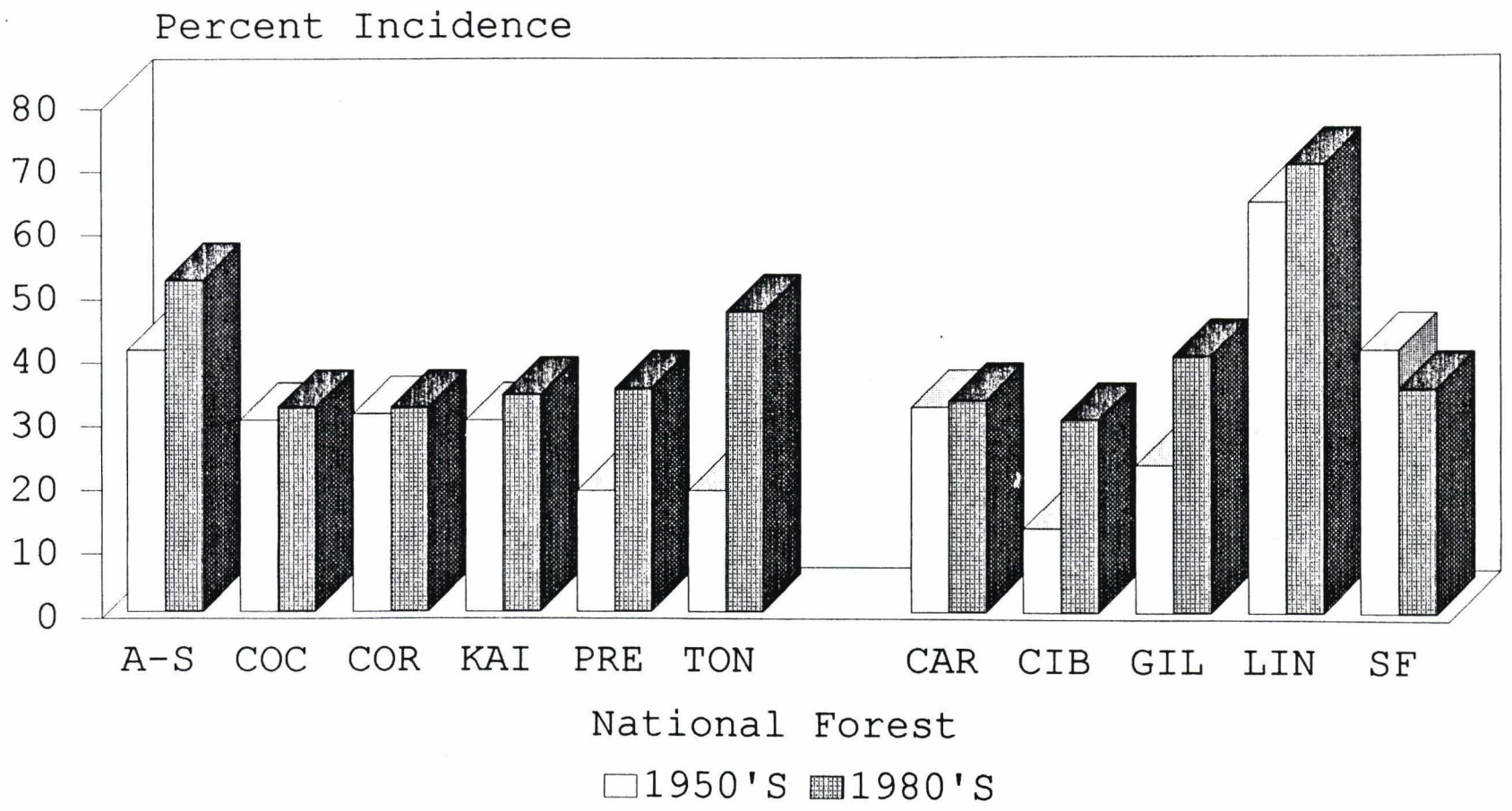

Figure 2

Annual Root Disease Related Mortality

in Southwestern Conifer Stands

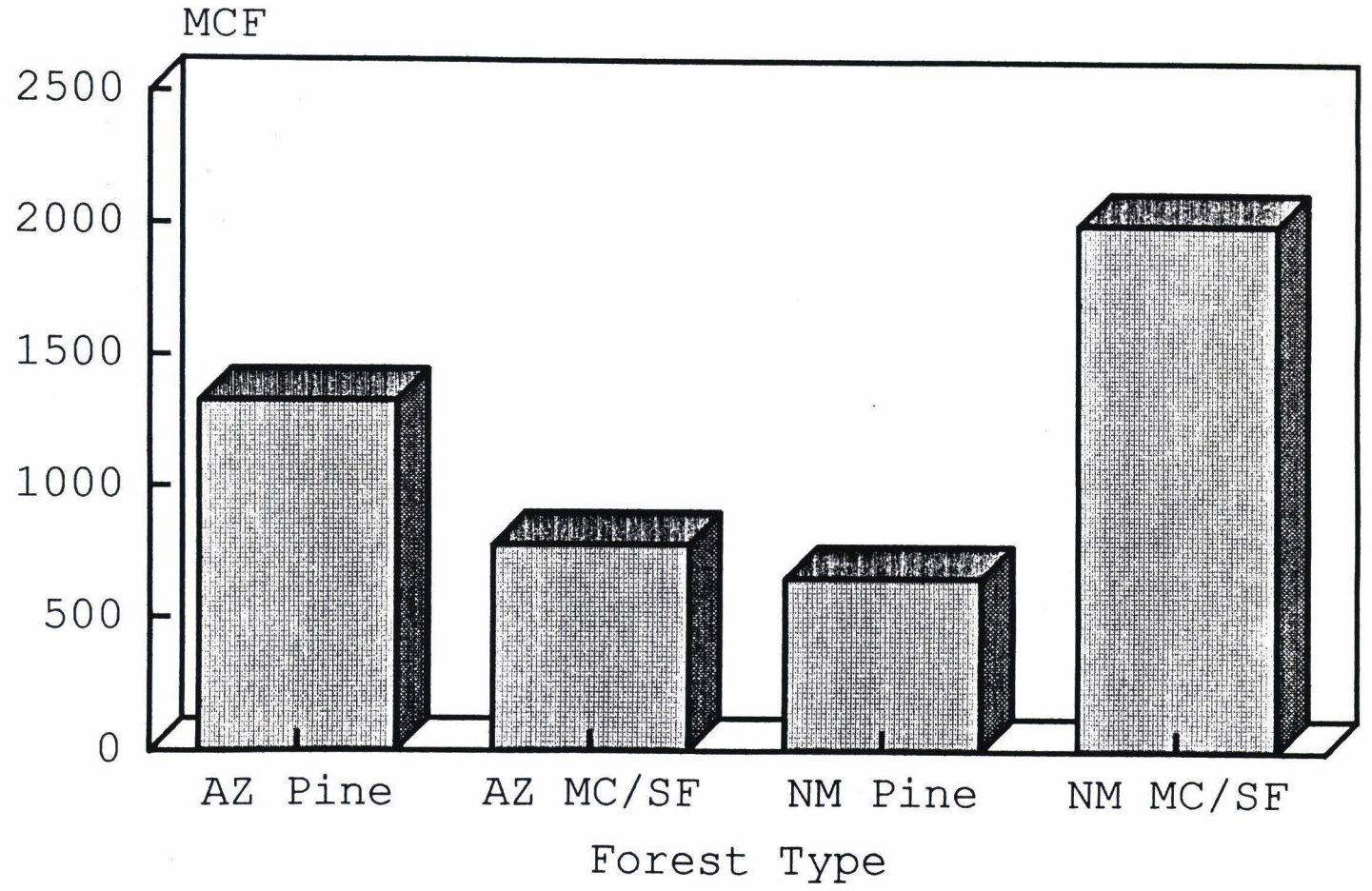

Figure 3 (expanded after Wood 1983)

Western Spruce Budworm Defoliation

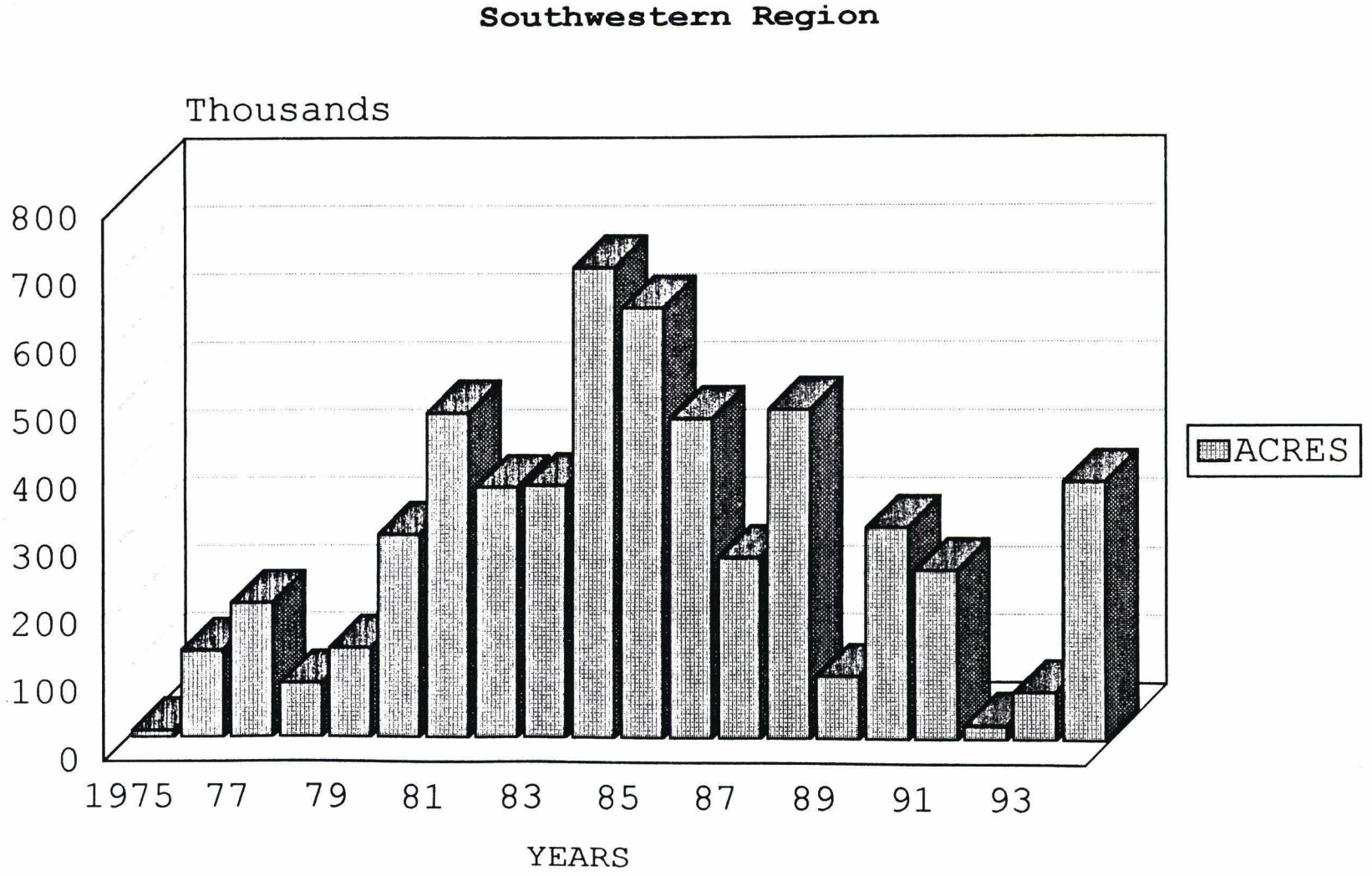

Figure 4

ACRES INFESTED WITH BARK BEETLES

IN ARIZONA AND NEW MEXICO

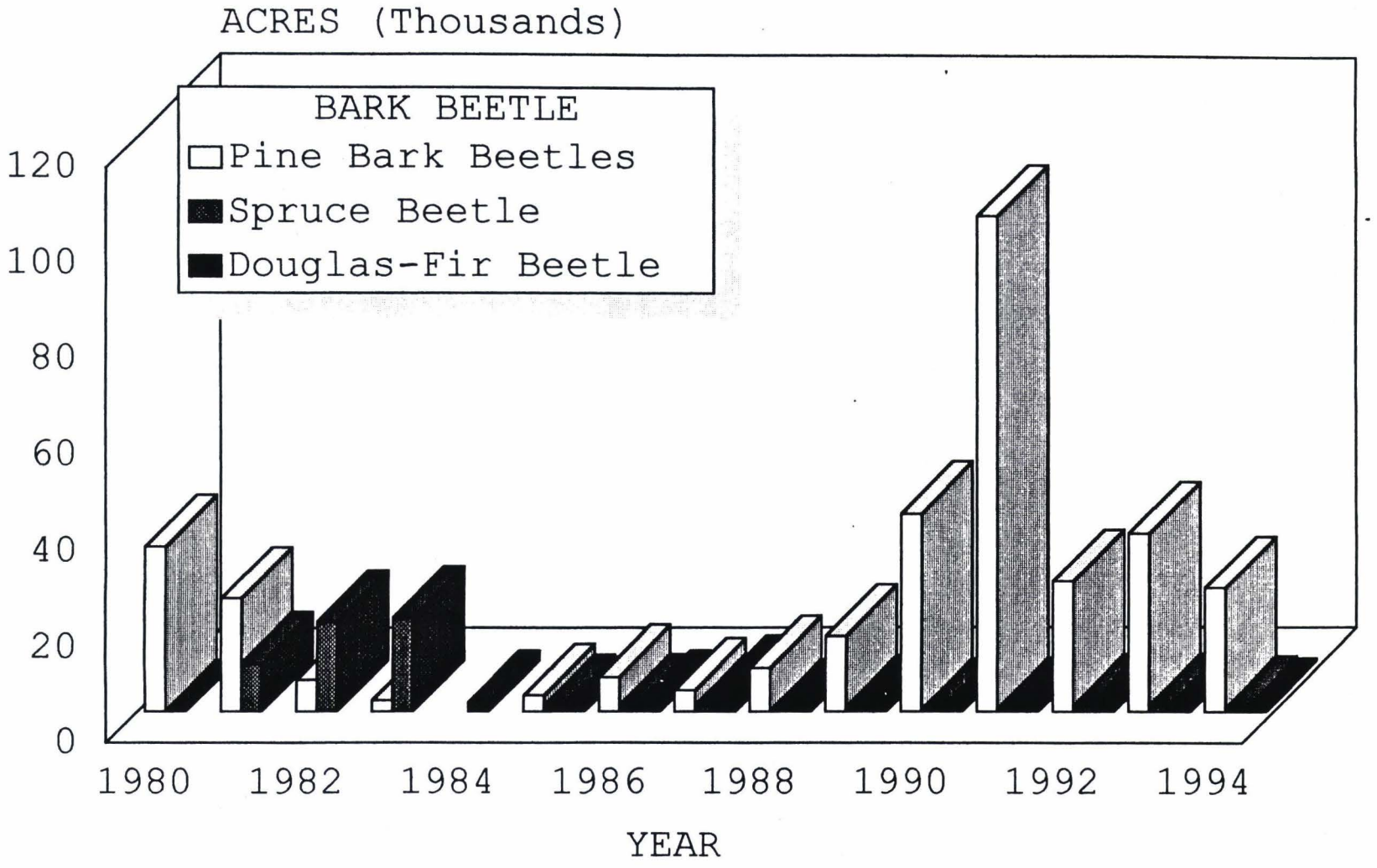

Figure 5